SCHWERIN

Impermeability of Concrete

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IMPERMEABILITY OF CONCRETE

BY

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THESIS

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

ARTHUR SCHWERIN

ENTITLED IMPERMEABILITY OF CONCRETE

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Civil Engineering

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INTRODUCTION.

The subject of impermeability of concrete has been a matter of investigation ever since concrete has come into general use. The best method of eliminating the displeasing and harmful effects due to the seepage of water through mortars and concrete is a live topic among practicing engineers, especially those engaged in the construction of dams, reservoirs and tunnels.

Several different methods of water-proofing have been devised, which may be roughly divided into three classes:-

1. Methods involving the use of bituminous compounds, the water-proofing materials being entirely separate and distinct from the concrete.

2. Washes applied to the surface of the finished concrete.

3. Compounds added to the concrete in mixing and thus forming an integral part of the mixture.

A fourth method together with results of laboratory tests will be found in the following pages. The object of these tests was to determine what proportion of the different ingredients should be used to secure the greatest degree of impermeability without the use of so-called water-proofing materials.

Permeability should not be confused with porosity. The former is that property of a material which permits a liquid under pressure to pass through it, whereas porosity is the power of a material to absorb a liquid and retain it within its pores.

Before planning his experiments the writer examined the available literature on this subject, and in the following pages the results of two of the latest investigations will be briefly presented.

The subject of the impermeability of concrete will be discussed here in the following order:-- I. Review of Compiled Data; II. Materials Used; III. Description of Volumetric Tests; IV. Description of the Permeability Apparatus; V. Results of Tests.

I. REVIEW OF COMPILED DATA.

Mr. S. E. Thompson and W. B. Fuller made a series of tests a few years ago for the Acqueduct Commission of the City of New York upon the density and transverse strength of concrete beams mixed in varying proportions. In connection with these tests, the beams were also tested for impermeability.

After the beams had been broken a piece 6 x 6 x 17 inches long was scored on all four sides and then placed under water for twenty-four hours. When taken from the water it was placed in a wooden mold in an upright position and neat cement was poured around the edges. The surface of the test specimen after it was finished was covered with damp sand and twenty-four hours were allowed for the cement to set.

The specimen was then placed upon a tin funnel set in a wooden pail, resting upon a suitable foundation. Water entered the specimen through a one-half inch nipple connected with a union coupling to the bottom of an air pressure tank. Varying pressures were secured by means of the tank, and any desired pressure could be obtained for any length of time. The time was read by means of a stop watch reading to one-fifth of a minute.

As a result of these tests the authors conclude that:-

"The permeability or flow of water through concrete is less as the percentage of cement is increased, and in a very much larger inverse ratio.

The permeability is less as the maximum size of the stone is greater. Concrete with mazimum size stone of two and one quarter inches in diameter is, in general, less permeable than that with

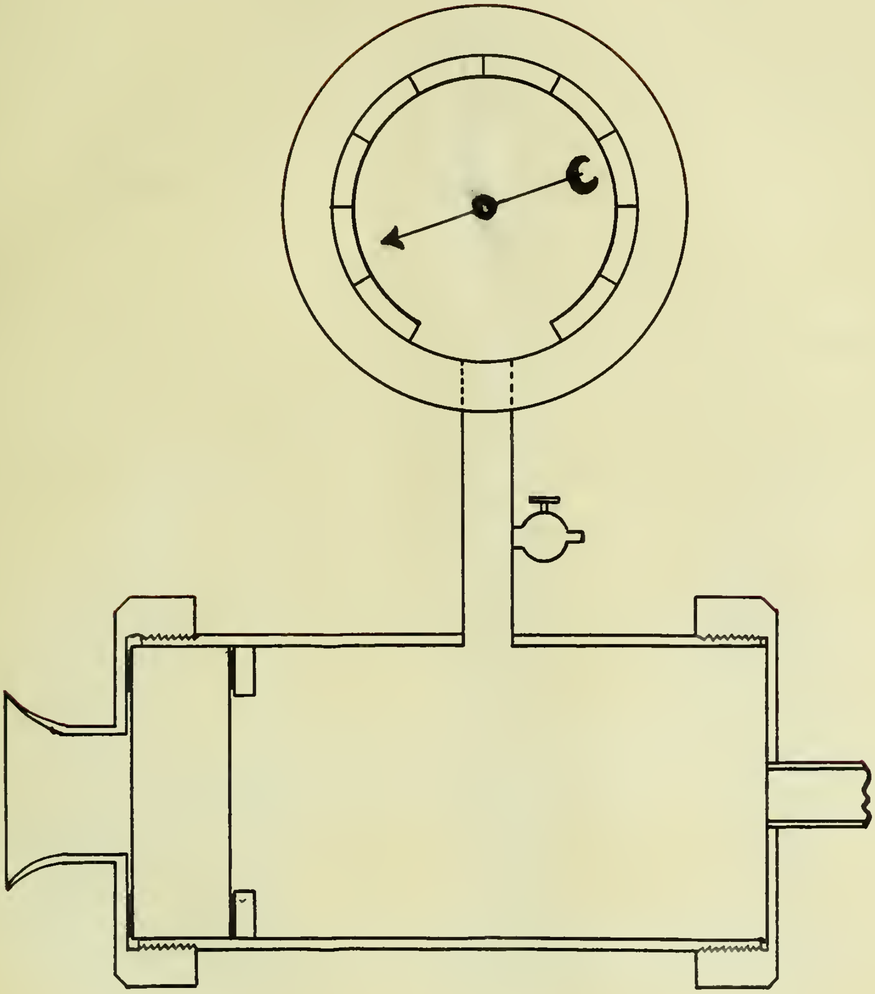
one inch maximum diameter stone, and this is less permeable than that with one-half inch stone.

"Concrete of cement, sand, and gravel is less permeable than concrete of cement, screenings and broken stone, that is, for equal permeability, a slightly smaller quantity of cement is required with rounded aggregates like gravel than with sharp aggregates like broken stone.

"Concrete of mixed broken stone, sand and cement is more permeable than concrete of gravel, sand and cement and less permeable than similar concretes of broken stone, screenings and cement; that is for water tightness, less cement is required with rounded sand and gravel than with broken stone and screenings.

"The permeability decreases materially with age; increases nearly uniformily with the increase in pressure and increases as the thickness of the concrete decreases, but in a much larger inverse ratio.

In volumne VI of the Proceedings of the American Society For Testing Materials, Mr. W. Purvess Taylor presents the results of tests conducted by the Water-proofing Committee. "The apparatus used was made from a three and one quarter inch brass pipe, having a ring one-half inch wide fastened one inch from the end of the pipe. Rubber packing three-sixteenths of an inch thick was placed against this ring and also over the specimen so that by tightening the outer nut the test piece is securely locked into position. The orifice in the outer nut was two inches in diameter. A sketch giving a more detailed view is shown on the next page.



APPARATUS USED BY MR. W. P. TAYLOR

The most important conclusion reached was in regard to the storage of test specimens. The permeability of concrete is much effected by its manner of storage, whether in air or in water; storage in air increases the permeability, while storage in water decreases it. The following example shows the effect of varying treatment upon a test specimen:

Treatment	Permeability
7 days in water, 14 days air	150 c.c. per min.
48 hours more in water	123 " " "
72 " " " "	127 " " "
24 " " " air	133 " " "
72 " " " "	172 " " "
96 " " " "	200 " " "
24 " " " water	163 " " "
72 " " " "	150 " " "

II. MATERIALS USED.

The cement used in conducting the experiments for this thesis was Chicago AA Portland Cement. The properties of this cement are shown in Table 1 below.

TABLE 1. TEST OF CEMENT.

FINENESS			TENSILE TEST		
Sieve No.	Amount Retained		Briquette Number	Breaking Load in Pounds	Age in days
	Grams	Per Cent			
74	11.5	1.15	1	880	28
100	19.5	1.95	2	905	28
200	167.0	16.70	3	900	28
Pan	802.0	80.20	4	890	28
Total		100.00	5	870	28
Specific Gravity 3.21					

The sand used was ordinary building sand obtained from the pits east of Urbana. Only sand which had passed the No. 10 mesh sieve was used in the following experiments. A sieve analysis of the sand is shown in Table II.

TABLE II. SIEVE ANALYSIS OF SAND.

Amount of Sand Used	Sieve Number	Amount retained	
		Grams	Per Cent
1500	16	318.1	21.21
	20	68.8	4.58
	30	349.2	23.28
	40	438.3	29.22
	60	269.7	17.98
	74	16.3	1.09
	100	19.9	1.33
	150	5.9	.39
	200	1.4	.09
	Pan	2.4	.16
Totals		1490.0	99.33
Specific gravity 2.667			

The stone used was Kankakee limestone of a light gray color, the same as is used by the University Experiment Station in their concrete tests. The stone was run through the revolving screens at the crusher in order to get rid of the screenings, and in the laboratory was run through a series of sixteen sieves, ranging in size from three quarter inch to No. 200 mesh. By having the sizes graded it was easy to make a mixture of any desired proportion. The percentages and sizes of the two batches of stone that were used in making the test pieces for the experiments described in this thesis are shown in Table III. The third column in this table gives the percentage of stone under three-quarters of an inch which was retained on the various-sized sieves, while the fourth column shows the percentages retained under a one-half inch maximum.

The values given in column three are shown graphically by the lower curve on Plate 1, and those in column four are shown graphically by the lower curve on Plate 2. The upper curves on these same plates are those representing the proportions for maximum density.

TABLE III. SIEVE ANALYSIS OF STONE.

Diameters of Stone	Diameter of Opening in Sieves	Percentage retained	
		Under 3/4"	Under 1/2"
1/2"	.50	47.76	100.00
3/8"	.375	27.31	52.19
1/4"	.25	15.81	30.21
3/16"	.1875	4.04	7.75
1/8"	.125	1.85	3.59
3/32"	.0937	0.56	1.07
#16	.045	0.35	0.68
#20	.034	0.06	0.12
#30	.020	0.22	0.43
#40	.016	0.12	0.24
#60	.0115	0.13	0.25
#74	.0071	0.05	0.10
#100	.0058	0.10	0.19
#150	.0036	0.16	0.32
#200	.0027	0.09	0.18
Pan		1.41	2.68
	Totals	100.00	100.00

Specific Gravity 2.612

III. VOLUMETRIC TESTS.

For the purpose of determining the density of the mixtures used, volumetric tests were made. These tests followed the general principles laid down by the French Commission in 1894, the volumnes were calculated by methods used by M. R. Feret, the eminent French investigator.

In making the volumetric tests only the graded sizes of stone were used. The exact amount of each size was determined from the sieve analysis, and the mixture was made accordingly. All of the ingredients were proportioned by dry weight.

The mixing was done in a galvanized iron pan with an ordinary six inch trowel. Enough water was added so as to obtain a soft mushy mixture, which would hardly stand by itself, but could be easily handled. It was found by trial that when the concrete was mixed too dry that there was a tendency for air bubbles to form, which were a hindrance in finding the exact percentage of voids. Any free water appearing on the surface was carefully removed so that the quantity given in the density tables represents the actual amount of water in the specimen when it began to set.

The cylinder used in determining the volumnes was made of wrought iron, one quarter inch thick, four inches in diameter ten and one-eighth inches high, which was screwed into a one-half inch collar and bolted to a three quarter inch plate at the bottom flange. The mixed concrete, which had previously been weighed was poured into this cylinder and thoroughly rammed, an effort being made to secure the same amount of ramming as was

subsequently used in making the disks for testing purposes. As a final check upon the weight of the dry material, the cylinder containing the concrete and also the mixing tray and tools, were weighed. The amount of material adhering to them was determined and later on incorporated into the final calculations. Finally the distance from the top of the cylinder to the top of the concrete was measured in order to obtain the actual volumne of the rammed concrete.

The percentage of voids were calculated as follows:- The amount of the mix adhering to the tools was assumed to be made up in the same proportions as the mixture in the cylinder, and the net amount of each ingredient was figured by the method of proportions. Items 13 to 16 in Table IV. were obtained by dividing the net amount of the quantities in the mixtures by their respective specific gravities. The amounts thus obtained, represent the calculated volumnes. The difference between items 11 and 17 is the actual volumne occuppied in excess of the calculated volumne, and one hundred times this quantity divided by the calculated volumne represents the net percentage of voids in the mixture.

Volumetric tests were made of concretes in the following proportions: 1-2-3, 1-2-4, 1-2 1/2-3, 1-2 1/2--4. The results of these tests are shown in Table IV.

TABLE IV VOLUMETRIC TEST SHOWING

PERCENTAGE OF VOIDS IN CONCRETE.

1	Proportion of Mixture.	1-2½-3	1-2-4	1-2-3	1-2½-4	1-2-3
2	Maximum size stone, inches.	.5	.5	.5	.5	.5
3	Weight of Cement in ounces.	10	10	7.05	10	10
4	" " Sand " "	25	20	14.10	25	20
5	" " Stone " "	30	40	21.15	40	30
6	" " Water " "	6.5	7	4.23	8	6
7	Total Weight	71.5	77	46.53	83	66
8	Weight of Mix adhering	0.75	0.75	0.95	0.25	0.25
9	Net Cement in Mix	9.895	9.907	6.80	9.97	9.96
10	" Sand " "	24.73	19.81	13.8	24.92	24.92
11	" Stone " "	29.68	39.61	20.7	39.88	29.89
12	" Water " "	6.43	6.027	4.16	7.98	7.98
13	Depth of Concrete	4.125	4.375	2.625	4.75	3.625
14	Volumne of Concrete 9.62×(13)	39.7	42.09	25.25	45.69	34.9
15	Calculated Volumne of Cement	2.8	3.04	2.16	3.04	3.00
16	" " " Sand	9.28	7.44	5.18	9.37	9.37
17	" " " Stone	11.18	15.15	8.12	15.28	11.45
18	" " " Water	6.432	6.03	4.16	7.98	7.98
19	Total Calculated Volumne	29.69	31.66	19.67	35.67	31.80
20	Per Cent Voids (14-19÷14)×100	25.2	24.8	22.0	18.0	8.9

IV. DESCRIPTION OF APPARATUS.

The apparatus used was made after plans adopted by the Structural Materials Laboratory of the United States Geological Survey at St. Louis. A detail drawing of the apparatus is shown on Plate I. It consists of two iron castings between which the concrete test pieces or disks are placed. There are six bolts used, by means of which the disk is firmly clamped between the castings. The water entered through a one-half inch nipple screwed into the upper casting. A funnel was riveted to the lower casting to insure all of the water being caught. A glass jar was placed at the lower end of the funnel, which was allowed to protrude into the jar, thus making the jar more nearly air tight and thereby decreasing the evaporation.

The concrete disks were molded in iron rings, made of wrought iron pipe, six inches in diameter and two inches deep. These rings served not only as molds but also to keep the water from escaping through the sides of the test pieces when the latter were being tested. The disks were tested under two different pressures: a pressure of seven pounds was secured by connecting the apparatus to an overhead tank, and a fifty pound pressure was obtained by connecting the apparatus to the University water main.

The ingredients used in making the disks were all proportioned by dry weight, four combinations being used, viz. 1-2-3, 1-2-4, 1-2 1/2-4, and a special combination obtained by using the maximum density curve derived by Mr. M. H. McCoy, '08, in his thesis "Proportioning Concrete." The cement used was first weighed and then the sand was added. These two were carefully mixed dry with a trowel until the resulting mixture was of a uniform color and

showed nostreaks. The stone after being weighed was placed on top of the sand and cement. The water was added last, care being taken to saturate the stone, as it was found by trial that a better bond would result than if the stone were used dry.

After mixing the concrete was placed in the iron rings and tamped. Ordinarily the rings were filled at once with concrete, no attempt being made to introduce it in layers. The tamping was done with a one-half inch round tamper, shown in the illustration on page 25.

The top of the disks were leveled with a trowel and in some instances a neat cement mortar was flushed around the edges, leaving a clear space of five inch diameter in the middle. No practical benefit, however, was derived by the use of this cement, since it was found possible by using a heavy enough gasket to secure a water tight joint. Two disks of each composition were made, one to be tested under low pressure and the other under high pressure.

After being molded the disks were covered for twenty-four hours with a damp cloth, and then they were placed under water and allowed to remain until tested.

[illegible]

[illegible]

V. RESULTS.

Table V. gives the quantity of water per day passing through each disk. One of the most noticeable features of this table is the varying results obtained from different disks made at the same time and under the same conditions. Disks #13 and #14 may be taken as an example. They were both made at the same time and from the same materials. Disk #14 when tested under low pressure proved impermeable and under high pressure showed only slight traces of percolation. On the other hand disk #13 under high pressure allowed 693 grams of water to pass through. The writer is unable to offer a satisfactory explanation for this. Mr. W. P. Taylor states that the permeability test of cement is more effected by small deviations of method than probably any other test to which cement is subjected. It may be that the bond between the disk and the iron ring was not as firm in disk #13 as in #14 and that possibly this allowed a considerable quantity of water to pass around the edges of the test specimen rather than through the disk itself.

Disk #2 under low pressure and disk #18 under high pressure permitted the water to run through in such large quantities that it was not thought practical to subject them to an extended test.

Disks #15 to #18 inclusive were made by using McCoy's maximum density curve. The results obtained were not at all of a satisfactory nature, owing to the fact that his curve was derived for a two inch stone, whereas that actually used was one half inch, in consequence of which there was an excess of fine material in the mixture. The maximum density curve spoken of, is derived by drawing an ellipse, whose equation is $(y - 7)^2 = \frac{b^2}{a^2}(2ax - x^2)$,

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

TABLE V PERCOLATION IN GRAMS.

Disk No.	Composition: Proportion	Composition: Max. Size Stone	Composition: Per Cent Water	Composition: Per Cent Voids	Grams Water Passing Through per Day: Low Pressure: Age Days	Low Pressure: 1st	2nd.	3rd.	4th	5th	6th.	7th.	Total	High Pressure: Age Days	High Pressure: 1st.	2nd.	3rd	4th	5th	6th	7th	Total
1	1-2-3	3/4"	6.43	8.9	21	31	117	120	72	21		55	416									
2	1-2-4	3/4"	6.18		21		(See results).															
3	1-2-3	3/4"	8.0	8.9	42			none														
4	1-2-3	3/4"	8.0	"	7	8	16	6.8	9.4	5.0		7.	49.2	14	49	61	59	54		307	41	571
5	1-2½-4	3/4"	8.0	18.0	21	0	6	6	6	0	0	0	18.0									
6	1-2½-4	3/4"	8.0	"	7	2	3.1	1.5	1	1	.37	.68	9.15									
7	1-2-4	1/2"	9.0	24.8										7	18	9.4	5	3.5	3.5	2.3	2.2	44.
8	1-2-4	1/2"	9.0	"	7			none														
9	1-2-3	1/2	8.0	22.0										7	403	403	252	227	163	163	35	1646
10	1-2-3	1/2	8.0	"	7			none						14	30	15.9	10.3	8.6	10	7.5	7.5	89
11	1-2-3	1/2	10.0	"	–									7	24	8.2	2.0	.5	.5	–	–	35.2
12	1-2-3	1/2	10.0	"	7			none						21				none				
13	1-2½-3	1/2	9.0	25.2										7	275	125	67.5	55	59	55	40	676
14	1-2½-3	1/2	9.0	"	7			none						14	1	1	1		none			3
15	Maximum Density Curve	1/2	10.0	Not determined	7	206	28	26	20	19	15	15	329									
16		1/2	10.0											7	925	445	400	380	375	300	290	3115
17		1/2	10.0		28			none														
18		1/2	10.0	"	28											(See Results)						

TABLE VI PERCOLATION

IN OUNCES PER SQUARE INCH PER DAY.

Disk	Low Pressure							High Pressure						
No.	1st.	2nd.	3rd.	4th	5th	6th	7th.	1st.	2nd	3rd	4th	5th	6th	7th.
1	.114	.412	.451	.074	.103	.102	.264							
2														
3			none											
4	.029	.044	.03	.03	.015	.014	.011	.18	.224	.217	.198	1.13		.15
5	0	.022	.022	.022	.029		.051							
6	.007	.011	.005	0	0	0	0							
7								.064	.030	.018	x	.026	x	.016
8			none											
9								1.48	1.36	.091	.084		1.06	.083
10			none					.102	.044	.034	.030	.034	.027	.027
11								.088	.030	.007	x	x	0	0
12			none							none				
13								1.08	.445	.181	.258	.160	.158	.126
14								x	x	x	0	0	0	0
15	.720	.095	.088	.068	.065	.051	.051							
16	-							3.14	1.51	1.36	1.29	1.27	1.02	.099
17			none											
18														

from zero to a point represented by one-tenth of the maximum size stone used. A tangent is drawn from this point to the one hundred per cent point, thus completing the curve; (see Plate I for an illustration.)

Another noticeable feature is the effect of age upon the percolation. Although no direct attempt was made to secure information on this point, still by inspection of the table it will be seen that the amount of water passing through decreased with the age of the test specimen. Disks #11 and #12 may be taken as an example. Disk #11 at the age of seven days was tested under high pressure, and after seven days showed a total percolation of 35 grams; disk #12 was not tested until it was twenty-one days old, and proved to be water tight.

Further it will be seen that the largest quantity of water passed through the first day, and that there was a gradual decrease in the amount of percolation during the time that the disk was under test. The writer advances two reasons for the above variation: first, that as the cement becomes older the bond between the cement, sand and stone becomes firmer, consequently this adhesive tendency decreases the amount of water passing through; second, the decrease of percolation is due to the action of the water passing through. The University water contains considerable silica, iron and calcium, which are held in solution and deposited upon the surface and interior of the disks. The action of the water may be said to be two-fold, mechanical as described above, and chemical. The chemical action is the more important of the two, and has the greater effect. The water acts upon the cement, forming a hydrate and thus closing the pores or voids in the

concrete, thereby decreasing the permeability.

The percolation also depends upon the pressure, and varies very nearly directly as the pressure applied. As but two pressures could be obtained, this observation is, of course, not conclusive, but bears out the results obtained by other investigators.

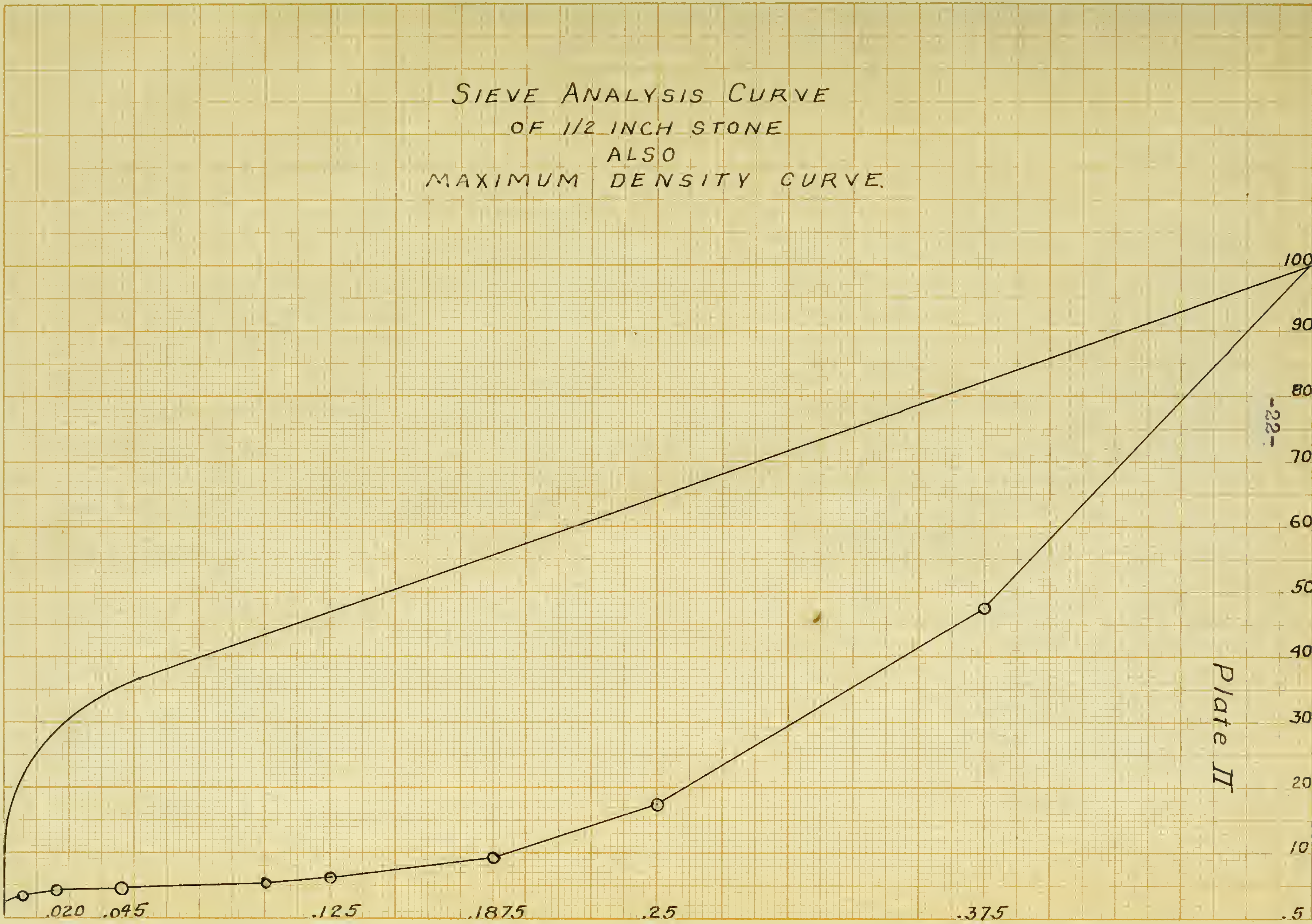
It was hoped by these tests to determine a relation between the permeability of concrete and its percentage of voids. The percentage of voids was obtained as explained on page 12, but since the disks were made at different times it is possible that the conditions were not exactly the same each time, so that the percentage of voids given by the volumetric tests do not correctly represent the percentages of voids in the disks. Owing to the irregularity of the results shown in Tables V. and VI, no reliable conclusions can be drawn respecting the percentage of voids. No attempt was made to secure information in regard to the values of the different proportions of material used in the concrete, and they are mentioned here only to show by what mixtures the different percentages of voids were obtained. The writer would suggest that in future experiments, the volumetric tests be made in the iron rings and at the same time the disks are molded, and then the percentages of voids found will be that of the test specimens themselves.

The results obtained tend to show that the proportion of water used has an effect upon the percolation, the wetter concretes being the more impermeable. Disk #10 containing 8% of water showed a total percolation of 89 grams in seven days, while disk #11 containing 10% of water showed but 35 grams in the same period. There are two possible explanations for this phenomena: The first

is that when an excess of water is used, that water bubbles are formed surrounded by cement, which offer resistance to water entering from the outside. The second explanation is that 8% of water is not sufficient to make a thoroughly plastic concrete, and that all of the sand grains and pieces of stone are not coated with sufficient cement grout.

The writer believes that it is possible to decrease if not entirely eliminate the displeasing effects caused by the seepage of water through concrete by a correct proportioning of the cement, sand, stone and water as determined by the maximum density curve, although the tests made were not sufficiently extensive to warrant this conclusion.

Plate II


SIEVE ANALYSIS CURVE
OF 1/2 INCH STONE
ALSO
MAXIMUM DENSITY CURVE.
100
90
80
70
60
50
40
30
20
10
.5
.020
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.125
.1875
.25
.375

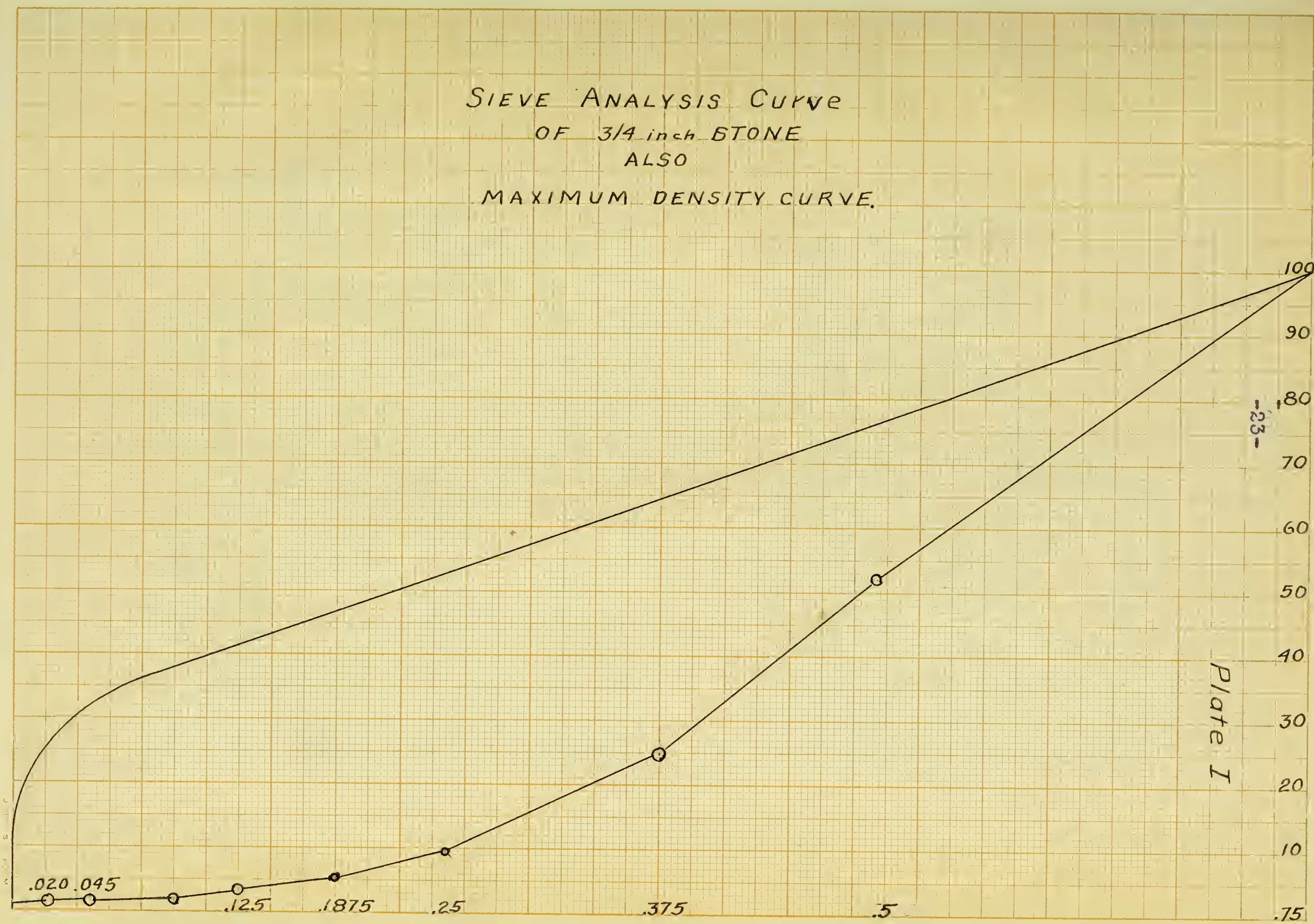
Sieve Analysis Curve
of 3/4 inch Stone
Also
Maximum Density Curve.
100
90
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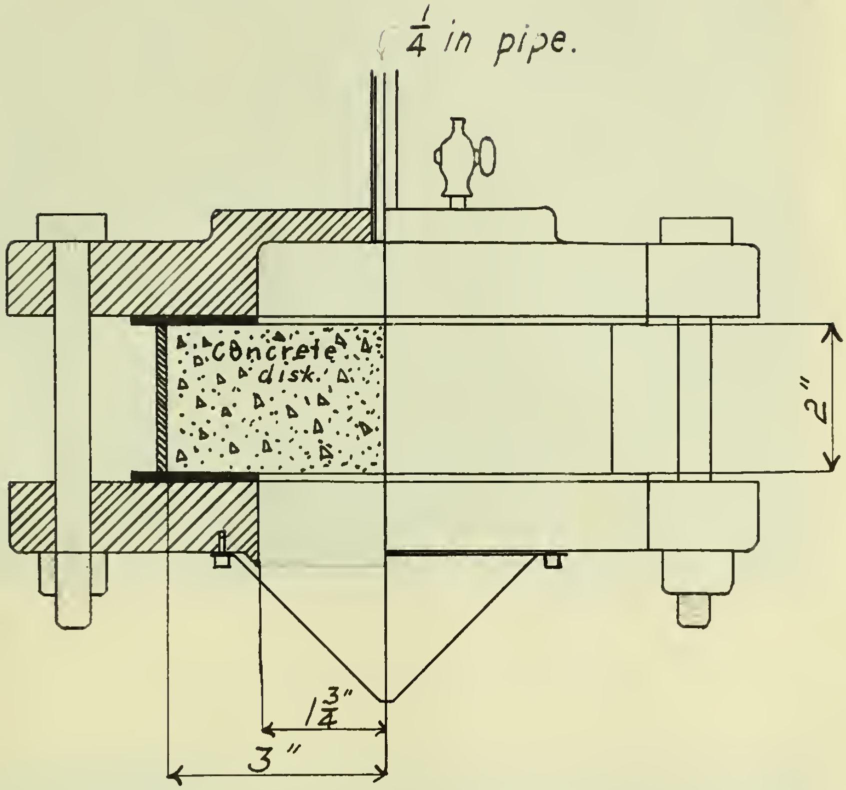
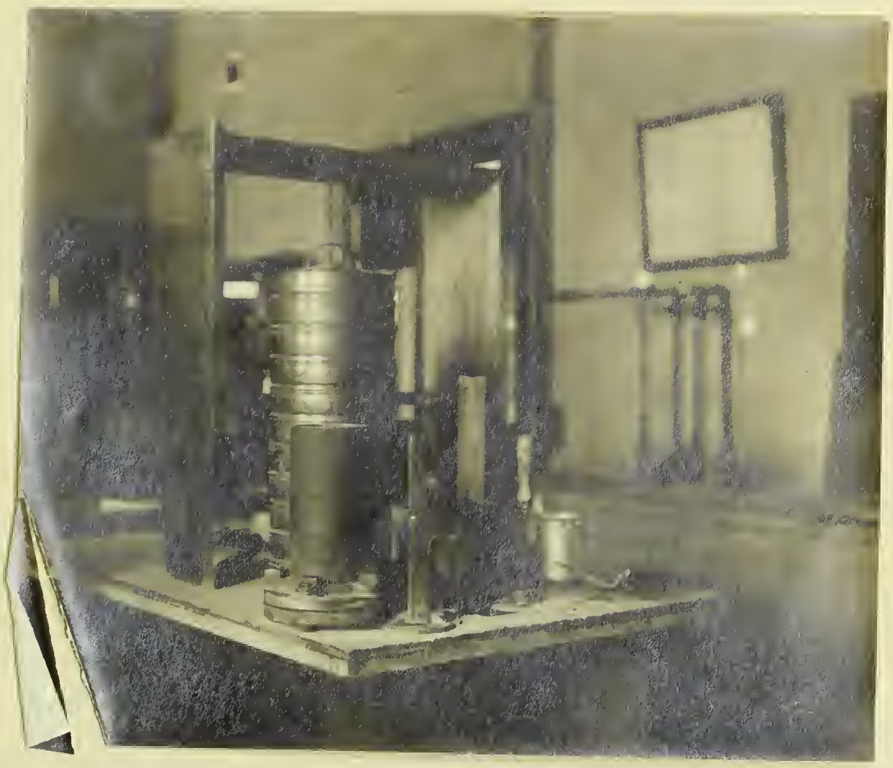
Plate I



SECTION OF IMPERMEABILITY APPARATUS

VIEW OF APPARATUS



VIEW OF TOOLS USED